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ANNE BEERENWINKEL, ILKA PARCHMANN and CORNELIA GRÄSEL

CONCEPTUAL CHANGE TEXTS IN CHEMISTRY TEACHING: A STUDY ON THE PARTICLE MODEL OF MATTER

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ABSTRACT. This study explores the effect of a conceptual change text on students' awareness of common misconceptions on the particle model of matter. The conceptual change text was designed based on principles of text comprehensibility, of conceptual change instruction and of instructional approaches how to introduce the particle model. It was evaluated in an empirical study with 214 students. Students' learning was measured with a pre–post-test design. Item response theory was used for analysing students' answers. We found that reading the criteria-based text fostered students' awareness of common misconceptions about the particle model and yielded overall improved results as compared to reading a traditional text.

KEY WORDS: chemistry education, conceptual change, model understanding, particle model, science texts

Introduction

According to the constructivist model, learning can be seen as an active, goal-oriented process. The individual's prior knowledge influences profoundly what is noticed about the environment and how this information is processed (Bransford, Brown & Cocking, 2000; Cobb, 1994). When students enter science classes, they bring along a plethora of ideas about scientific phenomena which are often not compatible with the scientific view. Different terms are used in educational literature to refer to these ideas such as preconceptions, alternative ideas or misconceptions[1] (see Duit, 2009). A non-addressing of these ideas may entail learning difficulties (e.g. Driver, Guesne & Tiberghien, 1985; Nakhleh, 1992; Treagust, Duit & Nieswandt, 2000). Additionally, both physics and chemistry use highly abstract concepts to explain phenomena. Not only that students have to deal with abstract ideas such as atoms, molecules or bonding but they also have to become skilled in using different kinds of models to connect these ideas with observable phenomena. It has been repeatedly shown that building appropriate model understanding is a highly intricate process (e.g. Grosslight, Unger, Jay & Smith, 1991; Mikelskis-Seifert, 2002; Nakhleh & Samarapungavan, 1999; Nakhleh, Samarapungavan & Saglam, 2005; Parchmann & Schmidt, 2003; Treagust, Chittleborough & Mamiala, 2002).

One of the major research questions in science education research is how to influence traditional science teaching in order to support students in overcoming these learning difficulties. One approach which is based on current theories of teaching and learning suggests a more student-centred classroom that encourages self-directed learning (Bransford et al., 2000; Parchmann, Gräsel, Baer, Nentwig, Demuth, Ralle & the ChiK Project Group, 2006). This requires a teaching approach which offers students the possibility to work independently, combined with phases of instruction and reflection. Different information sources are used in this context such as science books, computer programmes, experimental procedures or the Internet. The quality of the textual material that is given to the students thus becomes a pivotal aspect of preparing supporting and challenging learning environments.

Against this background, the present study investigated whether a criteria-based conceptual change text on the particle model of matter supports students better in overcoming common misconceptions than an ordinary textbook text.

State of Research

Conceptual Change

Conceptual change research is concerned with the questions how misconceptions develop and how they can be addressed in instruction. This research field has its roots both in cognitive science and in research on science education (Vosnidaou, 1999). The range of investigation is comprehensive and widespread in both fields. In the following, only some general aspects and results are outlined (for literature reviews, see, e.g. Duit, 1999; Hewson, Beeth & Thorley, 1998; Limón, 2001; Vosnidaou, 1999).

Despite almost 30 years of research on conceptual change, there is still no common agreement on how to interpret the notion of concept. While the term ‘concept’ is often used as a synonym for ‘category’, we agree with DiSessa & Sherin (1998) who argue that within science education the notion of concept is used in a much broader sense. Following White’s (1994) interpretation, the notion of concept is regarded in this article as a synonym for ‘conception’, namely large knowledge structures in which main aspects of a certain field are connected in multiple ways. These knowledge structures enable the individual to find domain-specific explanations and solutions to problems. Conceptual change processes can roughly be defined as learning paths from everyday conceptions or alternative ideas which have been developed under instruction towards scientific concepts. Ideas are combined and integrated into a broader network of conceptual explanations. There are different approaches how to theorise these paths. A popular approach in science education is Vosniadou's theory which describes conceptual change as a change of deeply entrenched presuppositions and beliefs. Students are assumed to construct mental models to solve problems. The formation of these models is supposed to be constrained by the individual's prior knowledge. When learners are confronted with a piece of information that conflicts with one of their presuppositions or beliefs, it is suggested that instead of changing the prior assumption, a so-called synthetic model is formed. This mental model satisfies both the new piece of information and the respective prior presupposition or belief. Synthetic models thus reflect consistent knowledge. However, they are faulty from a scientific perspective and thus called misconceptions. The gradual change from initial to more elaborated concepts is presumed to be expressed in gradual changes of mental models (Vosniadou, 1994; Vosniadou & Brewer, 1992). Other theories have been developed by, e.g. Chi, Slotta & de Leeuw (1994) or DiSessa & Sherin (1998). Despite different perspectives how to model the learning paths in detail, there is an overall agreement that conceptual change does not refer to a simple kind of learning such as a mere addition of facts. It is rather regarded as a learning process in which "conceptual structures … have to be fundamentally restructured in order to allow understanding of the intended" content (Duit & Treagust, 2003, p. 673).

Most of recent research regards conceptual change no longer as an exchange or replacement of ideas as it was interpreted at the beginning of conceptual change research. It is rather assumed that different concepts can co-exist (Duit, 1999). This perspective assumes that students do not generally abandon their previous ideas but that new concepts are added and connected in multiple ways with their prior knowledge. Using this lens, conceptual change can be interpreted as the development of metaconceptual understanding. This includes the development of meta-conceptual awareness, i.e. students know different concepts and they are aware of the strengths and limitations of the concepts. Additionally, students need to develop the ability to apply different concepts appropriately according to the respective context (Duit, 1999; Halldén, 1999; Vosniadou & Ioannides, 1998). For example, a model showing red and yellow spheres might support students in understanding the structure of copper sulphide. However, the idea of atoms or ions having a colour can impede the construction of a scientific understanding of chemical change. Fostering students' metaconceptual awareness thus appears to be one of the most important aspects in supporting lasting conceptual change processes. It seems crucial that students become aware of their own concepts and beliefs and of the similarities and differences between these ideas and the scientific ones (e.g. Mikkilä-Erdmann, 2001; Vosniadou, 1994). In order to support the construction of flexible knowledge, it is necessary for students to learn about a wide range of contexts to which the scientific concept can be applied more fruitfully than everyday ideas (Nieswandt, 2001). These aspects are particularly important when learning about scientific models. Modelling expertise is characterised by the ability to choose an appropriate model for the situation under consideration and to be aware of the strengths and limitations of the respective model.

The question how to engage students in conceptual change processes at the beginning is mostly answered by the strategy of cognitive conflict. Students are presented with anomalous information with the goal of motivating them to question their current concepts and to think about alternatives for explaining the phenomenon. A successful application of this method is, however, intricate, and a lot of factors have to be taken into account. It has been shown that students do often not or only partially change their concepts when presented with anomalous data (e.g. Chinn & Brewer, 1998; Mason, 2001). Nevertheless, the strategy of provoking a cognitive conflict by an experiment, text or discussion has proved to be a good starting point for conceptual change processes. A meta-analysis of Guzzetti, Snyder, Glass & Gamas (1993) showed it to be superior to approaches which introduced a new concept without challenging students' ideas. However, it is only one factor of many that have to be considered by teachers. For example, motivational variables such as students' self-efficacy beliefs and their goals for learning have to be taken into account (Pintrich, Marx & Boyle, 1993). Teachers are challenged to prepare environments so that the anomaly is interesting and meaningful to the students (Limón, 2001).

Generally, the work on students' ideas has shown that there are no simple recipes—neither for research nor for instruction. The preparation of learning environments to foster conceptual change requires careful selection of learning opportunities. Texts can be used as one of several tools in this context. It has been found that texts which present and refute misconceptions support students better in understanding the scientific content than reading common, non-conceptual change texts (e.g.

Alvermann & Hague, 1989; Guzzetti et al., 1993; Mikkilä-Erdmann, 2001; Wang & Andre, 1991). Most of the studies on conceptual change texts have been conducted in the field of biology, physics or geography, neglecting the area of chemistry education. Examples for empirical research in the field of chemistry (acid and bases and electrochemical cells, respectively) are the studies by Çakir, Uzuntiryaki & Geban (2002) and Yuruk & Geban (2001) who found positive effects for the application of conceptual change texts in the classroom. It is not clear, though, whether these effects were due to the texts or to other factors such as the discussions in the classroom.

As the present study is concerned with conceptual change texts for chemistry education with particular focus on the particle model, the section below summarises research on students' difficulties in learning about the particulate nature of matter.

Difficulties in Learning About the Particle Model

An important aspect of science education is that students develop an attitude of asking questions about everyday phenomena and that they try to find explanations for these phenomena using scientific theories and models. The ability to use models appropriately is not only important for succeeding in science classes but also for participating successfully in social life, e.g. for analysing climate calculations or economy prognoses. Developing these skills is regarded as a main aspect of becoming scientifically literate (Gilbert & Boulter, 1998; OECD, 2006). Therefore, most chemistry curricula require students not only to become familiar with different models but also to develop an understanding of the nature of models (e.g. NRC, 1996). In the following, we focus on students' difficulties in learning about the particle model. Further reading on the nature of models can be found in, e.g. Bailer-Jones (2000), Gilbert & Boulter (1998), Justi & Gilbert (2000) or Van Driel & Verloop (1999).

Doing chemistry is characterised by permanent alternation between making observations on the macroscopic level and explaining these observations on the submicroscopic level using models. While experts, like teachers, are able to easily and often unconsciously jump between the different levels, novices, like students, have difficulties in understanding the relationship between model and phenomenon (De Jong, Van Driel & Verloop, 2005). Students are challenged to think on a highly abstract level when working with models. In order to facilitate these thinking processes, students are often presented with visualisation models such as pictures of Rutherford's atom model or small balls for visualising a particle model. When such "models of models" (Becker, Glöckner, Hoffmann & Jüngel, 1992, p. 410) are used in the classroom, it is important that students' do not equate visualisations of mind models with concrete models such as car models.

Overall, research has shown that the development of understanding of the nature of models and their role in science is a challenging process which takes time (e.g. De Jong et al., 2005; Harrison & Treagust, 2000; Mikelskis-Seifert, 2002; Treagust et al., 2002).

Misconceptions about the particle model in particular have been investigated intensively and reported frequently (e.g. Albanese & Vicentini, 1997; De Jong et al., 2005; Gabel, Samuel & Hunn, 1987; Harrison & Treagust, 2006; Nakhleh, 1992; Nakhleh & Samarapungavan, 1999). For example, it is very common for students to struggle with the fact of emptiness between the particles. It is difficult for them to accept that scientists use ideas about particles to explain macroscopic features and behaviour instead of the other way around. Seeing matter as continuous and attributing macroscopic properties to particles are common thinking patterns among students (Harrison & Treagust, 2006). Despite the development of experiments, visualisation models, computer simulations and whole teaching units intended to support learning about the particle model, studies repeatedly find that students have difficulties with building appropriate model understanding. It seems difficult for students to apply the particle model consistently across different substances (Nakhleh et al., 2005), and even university students have problems explaining daily phenomena using the particle model (Ayas, Ozmen & Calik, 2009).

Appropriate ideas about the nature of models in general are an important part of understanding the nature of science (e.g. Coll & France, 2005). Appropriate ideas about the particle model in particular seem to correlate with understanding chemical change. Results of a 3-year longitudinal study (students of 11 up to 14 years) suggest a relationship between the view of properties as *collective* properties of particles and an appropriate understanding of chemical change (Johnson, 1999). Transfer of macroscopic features to submicroscopic particles seems thus to be a misconception that may negatively influence the further learning process in chemistry classes.

Overall, there has been substantial research on students' misconceptions about the discrete structure of matter. To make these results useful for classroom teaching, they need to be extended "by developing and testing strategies for working with preconceptions, providing tools and techniques for teachers to work with in the classroom" (Bransford et al., 2000, p. 261). The empirical study presented in this paper addresses this aspect by investigating the effects of conceptual change texts on students' learning. The following section shortly addresses the challenge of designing comprehensible science texts.

Science Texts

Texts are an important tool for passing on scientific knowledge. Authors of scientific texts for textbooks, the Internet or scientific journals are concerned with the question what a ‘prototypical comprehensible science text’ should look like. Several decades of research have shown that it is impossible to answer this question in general. Text comprehensibility is not only dependent on the design of the text but also on the individual characteristics of the reader, e.g. his or her prior knowledge, learning strategies, interests or intentions. Text comprehension is thus modelled as the product of a text–reader interaction (Artelt, McElvany, Christmann, Richter, Groeben, Köster, Schneider et al., 2005). Thus, it is not possible to create *the* comprehensible science text. There are, however, guidelines for text design which have proven to rise the comprehensibility of a text in general. For example, the design of the text should support the reader in constructing a coherent mental representation by, e.g. following a logical sequence or providing summaries. The linguistic style should not be too challenging. Another example how to enhance text comprehensibility is to include stimulating features that foster deep processing, e.g. questions (Ballstaedt, 1997). Such general aspects are also important for the design of ‘conceptual change texts’ which try to take students’ alternative ideas into account. How these texts address misconceptions differs from case to case (see, e.g. Mikkilä-Erdmann, 2001; Wang & Andre, 1991). A general structure to which most of the conceptual change texts adhere may be described as follows (Chambliss, 2002):

1. Presentation of the naive ideas based on everyday experiences
2. Demonstration of the limitations of the naive ideas
3. Presentation of the scientific concept
4. Highlighting how the scientific concept addresses the limitations

The answers to the following questions are important indicators whether a text attempts to address commonly held ideas (AAAS, 2002):

1. Does the text address common misconceptions about the particle model explicitly?
2. Does the text present phenomena which challenge common misconceptions? If so, is the observation that students are assumed to expect explicitly compared to the actual observation?

3. Does the text explicitly ask students to reflect on their own ideas or on common misconceptions?

The particle model is a concept that is essential to chemical understanding but difficult to learn. Thus, it is important to know whether texts that address common alternative ideas support students' in becoming aware of these misconceptions.

Research Question and Hypothesis

The present study investigates the following research question: Does a criteria-based conceptual change text support students in building appropriate ideas about the particle model? The conceptual change text addresses misconceptions explicitly and explains comprehensively why the misconceptions are model-inconsistent. We thus expected the conceptual change text readers to show a higher increase towards model-appropriate answers than the traditional text readers.

Methods

Participants

The conceptual change text was evaluated in an empirical study with six classes of eighth grade and three seventh grade at the gymnasium[2] level at four different schools located in small cities in Germany. Two distinct grade levels were chosen due to differences between the federal states with regard to the beginning of chemistry instruction. Both the seventh graders in North Rhine-Westphalia and the eighth graders in Rhineland-Palatinate were in their first year of chemistry education. Students in both states had two chemistry lessons per week (45 min each), and the syllabi of the two states were highly similar in content. At the time of the study, all students were familiar with the particle model which is a main aspect in the introductory chemistry course in both states.

The analysis was based on 214 participants with valid tests for pre- and post-test comprising 146 eighth graders and 68 seventh graders, 125 male and 89 female students. The average age was 13 years and 8 months.

Design and Procedure

The study was conducted with the nine classes described above at the end of the school year. The experiment took place in a regular classroom situation during two consecutive weeks. In the first week, students completed the pre-test (20 min). The following week, the students were randomly assigned to read the conceptual change text (111 students) or the traditional textbook text (103 students). After 15 min, the texts were collected, and the students were given the post-test (25 min). There was no other training than reading the conceptual change text and the traditional textbook text, respectively. It has to be considered that working on a pre-test can also trigger learning. However, this was true for both groups so that differences on the post-test can be attributed to reading the different texts.

Instructional Material

Two text versions on the introduction of the particle model were used in the study: a traditional textbook text (TT) and a conceptual change text (CT). Both texts were written in German language. The macrostructure of the two text versions is presented in Tables 1 and 2, respectively.

The conceptual change text was designed for the experiment according to specific criteria. Some of them are presented in the following: For deriving so-called framework criteria, results from research on conceptual change and text comprehensibility were used. As argued above, research on text comprehensibility has found specific text characteristics which rise the comprehensibility of a text in general, i.e. for most readers of the target group (e.g. Ballstaedt, 1997; Langer, Schulz von Thun & Tausch, 2002; Sumfleth & Schüttler, 1995). This knowledge was used to define linguistic characteristics for the design of conceptual change texts. Additionally, suggestions made by teachers in a prior study on how to improve chemistry textbook texts (Beerenwinkel & Gräsel, 2005) were included. Examples for framework criteria are as follows:

- If the limitations of a certain concept are demonstrated by providing anomalous information, the cognitive conflict should be meaningful and interesting to the students.
- Students' metaconceptual awareness should be fostered by explicitly contrasting scientific and alternative ideas.
- The text should have a clear structure both on the micro- and on the macro-level.

The development of content-specific criteria focused on the question how to address common misconceptions on the particle model. To approach this problem, we used theoretical models on conceptual change (e.g. Chi et al., 1994; Vosniadou, 1994) in order to explain the formation of

TABLE 1

Macrostructure of the traditional textbook text on the introduction of the particle model used in the study

Macrostructure of the traditional textbook text
Substances are built up of smallest particles (main headline)
No heading. Description of the experiment of mixing water and alcohol
The idea of particles. Presentation of the idea that water and alcohol are built up of smallest particles. Explanation of the experiment of mixing water and alcohol using the idea of particles
All substances are built up of smallest particles. Presentation of a particle model (without the assumption of constant motion)
The idea of spherical particles. Introduction of the notion of model. Presentation of the idea to think of the particles as spheres. Addressing of the misconception that models are copies of reality. Addressing of the misconception that features of visualisation models such as colour can be transferred to the particles
Models and reality. Extended description of the nature of scientific models
The motion of the smallest particles (main headline)
No heading. Information that the particle model can be used to explain further phenomena and that it has to be expanded for this purpose
The constant motion of the smallest particles. Presentation of the experiment of Brown. Expansion of the model by assuming constant motion. Explanation of the phenomenon using the particle model
No heading. Presentation of the phenomena of perfume flavour spreading throughout the room and of air mixing with bromine. Introduction of the notion of diffusion. Explanation of the phenomena using the particle model
Dissolving and crystallizing. Presentation of the phenomenon of salt dissolving in water and crystallizing by evaporation. Explanation of the phenomenon using the particle model
No heading; framed. Summary of the statements of the particle model

common alternative ideas. Based on the results of this analysis, instructional approaches (e.g. Fischler & Lichtfeldt, 1997; Grosslight et al., 1991; Mikelskis-Seifert, 2002; Treagust et al., 2000) how to introduce the particle model were reviewed and content-specific criteria were derived. These guidelines comprised both general and specific criteria. One of the general guidelines was, for example, to care for a clear distinction between the world of models and the world of perception in order to support students in understanding models as constructs of mind. The particle model is often introduced via the repeated division of a portion of a substance. One of the specific criteria suggested, for example, is to refrain from using this approach, but instead to highlight particles as (first) building blocks of matter in order to not reinforce the idea of

TABLE 2

Macrostructure of the conceptual change text on the introduction of the particle model used in the study

Macrostructure of the conceptual change text
Substances are built up of smallest particles (main headline)
You learn in this text … Presentation of learning goals
What you should know. Presentation of a rough definition of the notion of substance (prior knowledge)
A problem. Description of the experiment of mixing water and alcohol
The limits of our perception. Discussion about the limits of our perception. Introduction into the discreteness of the structure of matter. Introduction of the notions of building block, particle and model
How do we imagine the particles? Presentation of a particle model
When do particle models help? Information that the presented particle model can be used to explain specific phenomena
The mysterious volume reduction. Explanation of the experiment of mixing water and alcohol using the particle model
The mysterious disappearance of salt. Presentation of the phenomenon of salt dissolving in water. Addressing of the misconception that particles are small fragments of the substance. Explanation of the phenomenon using the particle model
No heading. Prompt to remind that the particle model is only an idea that helps to explain phenomena
Do the particles have a colour? Addressing of the misconception that the particles have the same features as the bulk substance
What is between the particles? Addressing of the misconception that air fills the space between the particles of a substance
Is there a “correct” model? Addressing of the misconception that a model is correct or false
At the end. Prompt to review each paragraph and to compare the main ideas presented in the text with one’s own ideas

particles as tiny, macroscopic pieces of a substance. To get a better impression of the implementation of the criteria, some examples from the newly developed conceptual change text are presented in Table 3.

The traditional text was taken from a chemistry textbook for secondary level I (Eisner, Gietz, Justus, Schierle & Sternberg, 2001, pp. 50 – 51). It was similar in structure and content to the conceptual change text. The subject of both texts was the introduction of the particle model. Both texts presented a particle model that assumes particles of pure substances being equal in size and mass. The assumption of attraction between the particles was not addressed in the texts. Both texts described models as means to explain phenomena and neglected the aspect of generating hypotheses using models. With regard to the structure of the texts, both started with

TABLE 3

Examples for criteria used to design the conceptual change text

Challenge misconceptions explicitly	*Refer to everyday life*	*Give metaconceptual prompts*
'What is between the particles? … Is there air between the particles?'	'You certainly know about vacuum-packed food or vacuum pumps ... In everyday life, however, we observe that there is air is between all objects.'	'Hence, what is between the water particles? How did you think of it before?'
'People often ask whether there is a correct particle model—a model that describes how the particles really look like.'	'In everyday life, you have had no problems in thinking of substances as continuously built so far.'	'Always remember that the particle model presented above is just an idea.'

the presentation of anomalous data, introduced the scientific concept in the following and explained afterwards different phenomena using the new concept. The conceptual change text included the same phenomena as the traditional text (mixing of water and alcohol, dissolving salt in water[3]), although fewer in number. To explain the dissolving process of salt using the particle model is sometimes seen as problematic. It is argued that this interpretation may contribute to the misconception of salts as molecular substances. To account for comparability, however, we adopted the example in the conceptual change text. On the other hand, using this example may not be problematic if later, when students have learnt about the idea of ions, the teacher re-addresses the phenomenon to discuss the strengths and limitations of the simple particle model. Another similarity was that both texts included metadiscussions about models (see Table 4).

There were also significant differences between the two text versions (see Table 5). The main difference between the conceptual change and the traditional text was the way in which misconceptions about the particle model were taken into account as can be seen in Table 6. Although the traditional text addressed some alternative ideas, there were more and longer text passages on misconceptions in the conceptual change text. Whereas the traditional text addressed some misconceptions in a rather indirect or abstract way, the conceptual change text addressed misconceptions explicitly. The

TABLE 4

Similarities between the traditional textbook text and the conceptual change text

Traditional text and conceptual change text
Same content
Similar macrostructure: *Anomalous data* → *Scientific concept* → *Phenomena*
Same type of phenomena
Metadiscussions about models

conceptual change text additionally provided comprehensive explanations *why* such ideas are regarded as misconceptions.

Headings within the conceptual change text also tried to focus students' attention to the disparity or overlap between their own ideas and the scientific view. For example, sections were headed by statements or questions such as "The limits of our perception", "Do the particles have a colour?", "Is there anything between the particles?" or "Is there a 'correct' model?" These questions are examples of common alternative ideas about the particle model as discussed above. In the sections following the headings or statements, features of the particle model were discussed while taking the according general misconception such as 'macroscopic properties are attributed to the particles' into account.

Due to inclusion of conceptual change components, the conceptual change text differed from the traditional text in its length. It comprised 1,165 words, whereas the traditional text was only 807 words long. Most studies on text design use revised texts that are longer than the texts used as comparison. The extension of 44% in this study falls within a moderate range (e.g. McNamara, Kintsch, Songer & Kintsch (1996), 20 – 98%;

TABLE 5

Differences between the traditional text and the conceptual change text

	Traditional text	*Conceptual change text*
Misconceptions	Few passages, addressed rather indirectly or abstractly	Many passages, addressed explicitly and concretely
Phenomena	Many	Few
Length	807 words	1,165 words

TABLE 6

Examples for the addressing of misconceptions in the traditional text and in the conceptual change text

Traditional text	*Conceptual change text*
Indirect versus explicit	
"Even when the smallest particles are lying closely side by side, there is empty space between them, i.e., there is nothing between the particles." (Eisner et al., 2001, p. 50, original version in German)	"What is between the particles? … In everyday life … we observe that there is air is between all objects. Thus, many of us have difficulties to imagine 'nothing' or 'empty space' … Is there air between these particles? No, because …"
Abstract versus concrete	
"When models are visualised and represented, aspects may occur which must not be transferred to the smallest particles. Peas and mustard grains have a colour, but our model makes no statement about a colour of the smallest particles of a substance." (Eisner et al., 2001, p. 50, original version in German)	"Are the particles coloured? What do you think is the colour of a copper particle? The substance copper is red and shiny. Thus, many people think that a copper particle is red and shiny. But beware! ... An individual particle has not the same features as the substance! It is important that you are aware that we cannot transfer observations that we make on objects of everyday life to the particles!"

Mikkilä-Erdmann (2001), 35%). If one does not compare the number of words but the number of characters, the conceptual change text exceeds only by 36% the traditional text.

Measurement of Students' Learning

As we intended to include a larger number of students into testing the conceptual change text, a paper and pencil test was chosen for measuring students' learning on the particle model. It included 18 closed-ended items which were partly based on those developed by Mikelskis-Seifert (2002) and two open-ended questions. This article discusses the results of the closed-ended items. Results concerning the open-ended questions can be found in Beerenwinkel (2007). The items referred to the most common misconceptions about the particle model which can be summarised under the following headings (see also Fischler & Lichtfeldt (1997, p. 5) and Mikelskis-Seifert (2002, p. 17)).

Nature of the Particles. Macroscopic behaviour and features are ascribed to the particles. Common ideas are that the particles have a colour, melt when heated, are motionless or stop moving after a while. Particles are often regarded as very tiny pieces having all the features of the bulk substance (e.g. “An individual sulfur particle is yellow.”).

Environment of the Particles. It is assumed that the space between the particles is filled with a continuous substance. Common ideas are that air fills the space between the particles or that water particles are embedded into water (e.g. “There is nothing between the individual particles that build up a substance.”).

Model Thinking. A naive-realistic view is taken. Common ideas are that there is a correct model and that models are copies of reality or provable facts (e.g. “If we make observations that cannot be described with the particle model you know, a new model should be developed.”).

Six items referred to model thinking in general (item label ‘mod’) and 12 items to the particle model in particular with eight items on the nature (item label ‘nat’) and four on the environment (items label ‘env’) of the particles (see Table 7 for details). The items of pre- and post-test were the same[4] and scored on a dichotomous scale (“I agree” (1), “I do not agree” (0)). Additionally, students stated their degree of certainty about their answer (“I am a sure” (1), “I am not sure” (0)). Before running the main study, a pilot study with two classes was conducted which showed that the students had no difficulties in understanding the texts or questionnaire and that the allotted time periods for reading the text and working on the items were appropriate.

Statistical Methods

Models of item response theory (IRT) were used to analyse the data.[5] The estimation of item difficulty parameters was based on the pre-test data, and students’ proficiency parameters were estimated for both pre- and

TABLE 7

Item ranking based on difficulty estimates

No.	*Item text*	*L*	*D*
1	There is nothing between the particles that build up a substance.	env3	595
2	Similar to a globe being a scaled down, simplified representation of the earth, the spheres in the particle model you know are a scaled up, simplified representation of how the particles look like in reality (r).	mod4	594
3	The individual particles building up frozen water have a lower temperature than those building up liquid water (r)	nat5	578
4	There is air between the individual particles that build up a substance (r).	env1	546
5	When water is heated to 30°C, the individual water particles have a temperature of 30°C (r).	nat4	527
6	An individual sulfur particle is yellow. (r)	nat2	524
7	When a balloon is entirely filled with the gas helium, then there is air between the individual helium particles. (r)	env4	470
8	The feature “shining” does not belong to an individual silver particle.	nat3	470
9	The nature of the particles differs from anything we know from everyday life.	nat7	455
10	The particle model you know is the only possibility how one can imagine the particles. (r)	mod6	443
11	The particles have the same features as the substance they are building. (r)	nat1	411
12	A particle model which is able to explain many observations describes how the particles look like in reality. (r)	mod5	408
13	If we make observations that cannot be described with the particle model you know, a new model should be developed	mod3	405
14	Our idea about particles is an invention by humans intended to explain certain observations.	mod1	402
15	The particles building up the substance sugar are tiny, white sugar pieces. (r)	nat6	388
16	It is possible that the features of the particles differ from those we assume in the particle model you know.	mod2	378
17	Since a rolling ball stops moving after a while, the particles will also stop moving sometime. (r)	nat8	367
18	There is liquid water between individual water particles. (r)	env2	350

L item label, *D* difficulty estimate (higher values indicate higher difficulty), *r* recoded items post-test using maximum likelihood estimation. Model fit and the quality of the test were evaluated following criteria presented in Wilson (2005) and Hambleton, Swaminathan & Rogers (1991). The evaluation was based on the pre-test data.

For testing on text design effects (CT versus TT), an ANCOVA was performed with the pre-test as a covariate for the post-test proficiency. Gender and teacher were additional between-subjects factors. We were interested in a main effect of text design and interaction effects between text design and gender or teacher, respectively. Since the proficiency estimates were given in logits, a common linear transformation was applied to get more convenient numbers. The proficiency estimates for the pre-test were transformed to make a mean of 500 and a standard deviation of 100. Post-test estimates and item difficulty estimates were transformed using the same equation (Hambleton et al., 1991).

Results

For evaluating the model fit and the quality of the questionnaire, different methods were used following criteria presented in Wilson (2005). Item and respondent fit were tested by comparing how much the actual residuals (difference of observed and expected scores) vary in contrast to how much they would vary if the data fit the model. To examine the reliability of the questionnaire, we analysed the according Wright map and investigated the standard error of measurement of students' proficiency estimates. The evaluation showed that a unidimensional model fitted the data appropriately. However, students' proficiency at the lower and upper end of the scale was estimated with a higher error than the proficiency of students in the middle of the distribution. Detailed results can be found in Beerenwinkel (2007).

Text Design Effects (ANCOVA), Mean Values and Degree of Certainty

The assumption of homogeneity of regression slopes was tested before running the ANCOVA. No significant interactions between the covariate (pre-test proficiency) and the factor levels were found. The equality of regression slopes for both treatment conditions (CT/TT) showed that there was no interaction between prior knowledge and text design. The correlation between pre-test proficiency and gain (difference between post-test and pre-test proficiency) was negative. Low prior knowledge students thus benefited more from working on the pre-test and reading a text than high prior knowledge students, although the correlation was modest (CT: $r = -0.34$, $p < 0.001$, TT: $r = -0.31$, $p < 0.01$). However, one has to consider that the test fell short in measuring the proficiency of high knowledge students.

As described above, the ANCOVA was run with the pre-test result as a covariate for the post-test proficiency. The model could account for 43% of variance (adjusted R^2). The covariate, pre-test proficiency, was significantly related to the post-test proficiency ($F(1, 190) = 56.49$, $p < 0.001$). There was a significant main effect of text design after controlling for the effect of pre-test proficiency, favouring the conceptual change text ($F(1, 190) = 42.28$, $p < 0.001$). There was no significant interaction between text design and any other independent variable. A main effect was found for the factor 'teacher' combined with a disordinal interaction between 'teacher' and 'gender'. However, these effects were only weakly significant and of no further interest within the scope of the research question investigated here.

Figure 1 presents a boxplot displaying the distribution of proficiency estimates of CT and TT readers for pre- and post-test. The outliers mainly point to the fact that there were some students who answered all or almost all items model consistently on the pre-test. The width of the CT post-test distribution and the difference between mean value and median are due to a peak of proficiency estimates around 800. CT and TT readers scored mean values of 502 and 498 on the pre-test, respectively. On the post-test, CT readers excelled TT readers with a mean value of 683 compared to a mean value of 551.

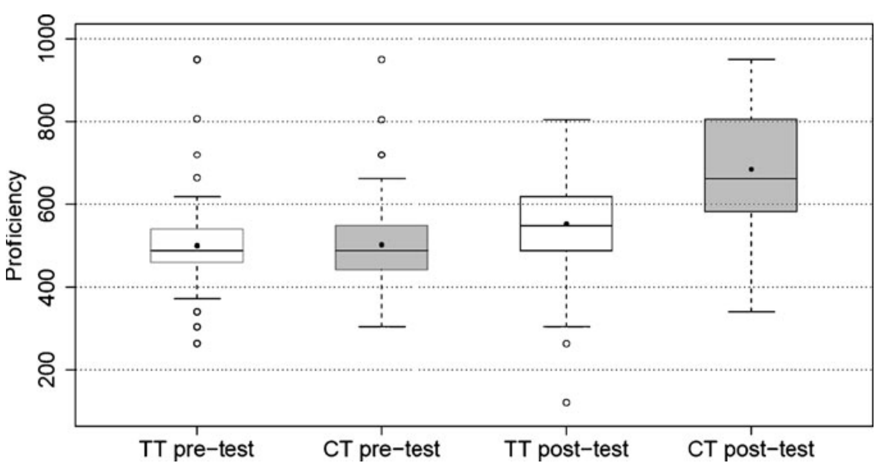

Figure 1. Distribution of proficiency estimates of traditional text and conceptual change text readers for pre- and post-test

The certainty with which students gave model-consistent answers also increased from pre- to post-test. The average proportion of the sure answers of the model-consistent answers was 56% for TT and 55% for CT readers on the pre-test, which were not significantly different. On the post-test, the proportion of CT readers increased to 80%, which was significantly higher than the proportion of 69% of TT readers (*t*-test, $p < 0.001$).

Analysis of Individual Misconceptions

The location of items about the environment of the particles (env) shows that it was easy for the students to deny the statement that liquid water fills the space between individual water particles (see item #18 in Table 7). Items referring explicitly to the idea of emptiness (item #1) or air (item #4) between the particles were found to be difficult, though. Items about model thinking in general (mod) showed a lower to moderate degree of difficulty (items #10, #12, #13, #14), with the exception of item mod4 (item #2), which asked specifically whether the spheres of the particle model are similar to a concrete model like a globe. The easiest item about the nature of particles (nat) referred to the idea that particles are in constant motion (item #17). Items with more general statements such as "The particles have the same features as the substance they are building" (item #11) showed a medium degree of difficulty. Items which gave specific instances for these general statements (e.g. "An individual sulfur particle is yellow.") are found at the upper end of the difficulty scale (item #3, #5, #6).

Summary and Discussion

A multidimensional approach was used for developing criteria for designing conceptual change texts for chemistry teaching. A text on the introduction of the particle model was designed according to the guidelines and tested with 214 students. The text focused on the relationship between model and phenomenon, addressed misconceptions explicitly, contrasted them with the scientific view and explained extensively why the scientific idea makes sense in specific situations. Results show that this text supported students better in building appropriate ideas about the particle model than a traditional text.

Does the Conceptual Change Text Support Students in Building Appropriate Ideas About the Particle Model?

An IRT model was used for estimating students' proficiency. The model not only provided an appropriate fit to the data but also showed that the test can be improved by increasing the quantity and range of items, especially towards the upper end of the difficulty scale. For testing on text design effects (conceptual change text versus traditional text), an ANCOVA was conducted which revealed a significant effect for text design, favouring the conceptual change text. The certainty with which students provided scientifically appropriate answers also showed a higher increase from pre- to post-test for the conceptual change text group. The analysis gave no indication that high or low prior knowledge students benefited more from one of the treatment conditions. This result is consistent with the findings of Mikkilä-Erdmann (2001) who showed that conceptual change processes are better supported by reading a conceptual change text compared to a traditional text for both high and low prior knowledge students. In the study presented here, in both groups, low knowledge students learnt more from reading the texts than high knowledge students. This can be explained in that the texts probably did not provide a lot of new information for high knowledge students. However, it has to be considered that the test fell short in measuring accurately high levels of proficiency. The proficiency increase of students who already scored high on the pre-test could therefore not be estimated with high confidence. The items used in the study were ranked according to their difficulty estimate. This ranking showed again how much students struggle with the thought of emptiness between the particles. Similarly, items referring to the idea that particles have features different from the macroscopic substance appeared at the upper end of the difficulty scale.

Generally, we cannot expect that reading a single text is sufficient to engage students in deep and long-lasting conceptual change processes. Teaching units that focus on conceptual change usually comprise many lessons taught over several weeks (e.g. Nieswandt, 2001; Vosnidaou, Ioannides, Dimitrakopoulou & Papademetriou, 2001). It may even take several teaching units before students are able to apply a scientific concept appropriately (Nieswandt, 2001). Texts are only one of several media that can be incorporated by teachers into a powerful learning environment. Against this background, it is very positive that a learning effect could be found after a treatment as small as reading a text. The results suggest that the conceptual change text helped students in becoming aware of alternative ideas and in distinguishing them from the scientifically accepted view, i.e. that the text supported students in developing metaconceptual awareness. However, for fostering long-lasting conceptual change processes, comprehensive teaching approaches are needed including conceptual change texts as only one of several tools.

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Notes

[1] Although the notion of misconception is one of the main notions in conceptual change research, it has often been criticised for implying that the corresponding ideas are regarded worthless. Here it is not used in this negative sense, but in a neutral way denoting ideas which conflict with the current scientific view.

[2] Secondary school comprising grades 5 through 12 or 13 which qualifies for university admission.

[3] The dissolving process is usually introduced as a physical process in the introductory chemistry course, and the interaction between, e.g. sugar molecules or ions with water molecules is discussed in later grades.

[4] Some items of the pre-test contained the phrase 'the particle model you know'. This phrase was replaced by 'the particle model described in the text' on the post-test.

[5] Software: GradeMap (Kennedy, Wilson, Draney, Tutunciyan & Vorp, 2005).

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Anne Beerenwinkel

Zurich University of Teacher Education (PH Zurich), Forschung und Entwicklung, MINT-Didaktik & System Schule
Waltersbachstrasse 5, 8090 Zurich, Switzerland
E-mail: anne.beerenwinkel@phzh.cht

Ilka Parchmann

Leibniz Institute for Science and Mathematics Education, Abteilung Didaktik der Chemie University of Kiel (IPN)
Olshausenstraße 62, 24098 Kiel, Germany
E-mail: parchmann@ipn.uni-kiel.de

Cornelia Gräsel

Lehrstuhl für Lehr-, Lern- und Unterrichtsforschung, Fachbereich G—Bildungs- und Sozialwissenschaften
University of Wuppertal
Gaußstr. 20, 42097 Wuppertal, Germany
E-mail: graesel@uni-wuppertal.de